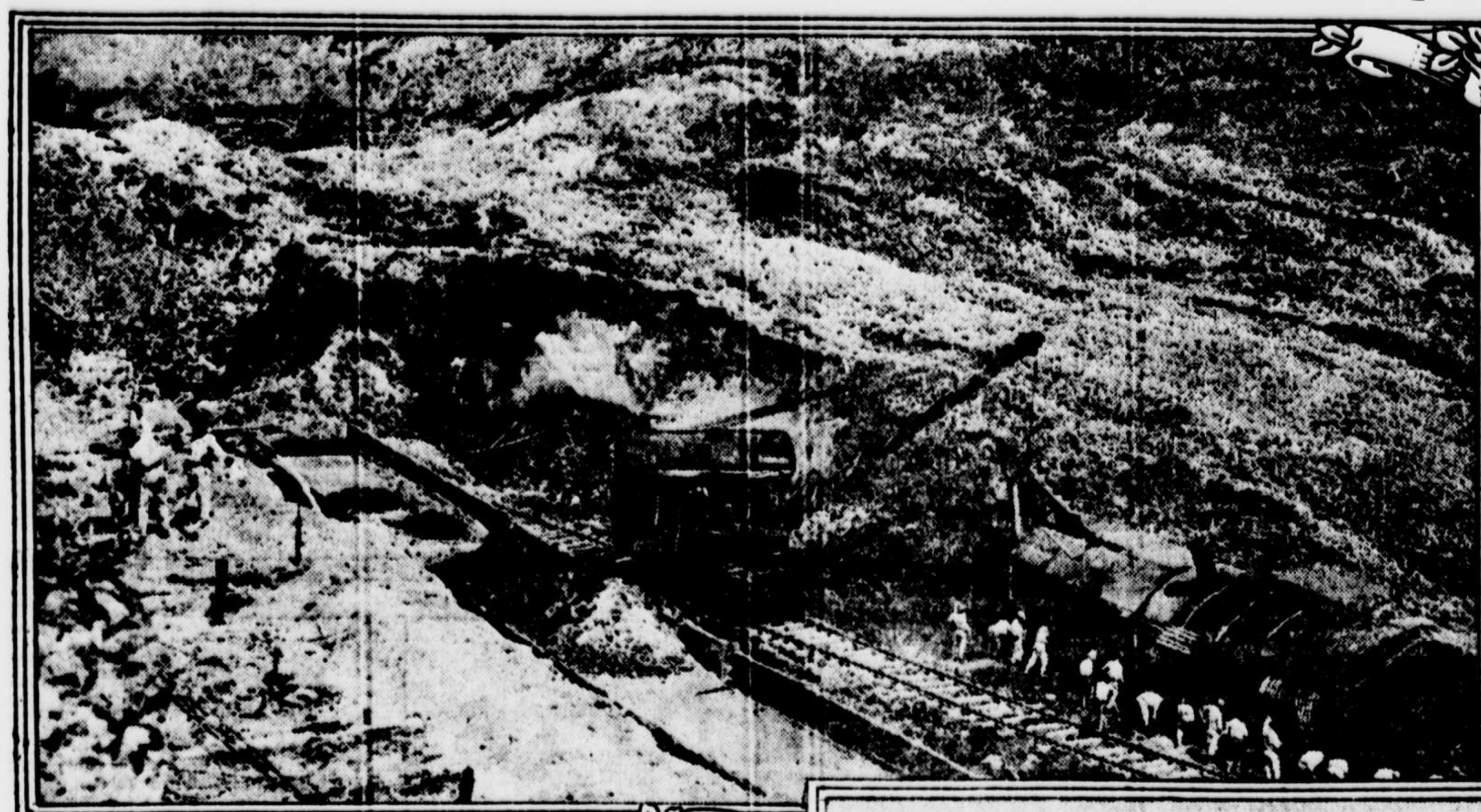
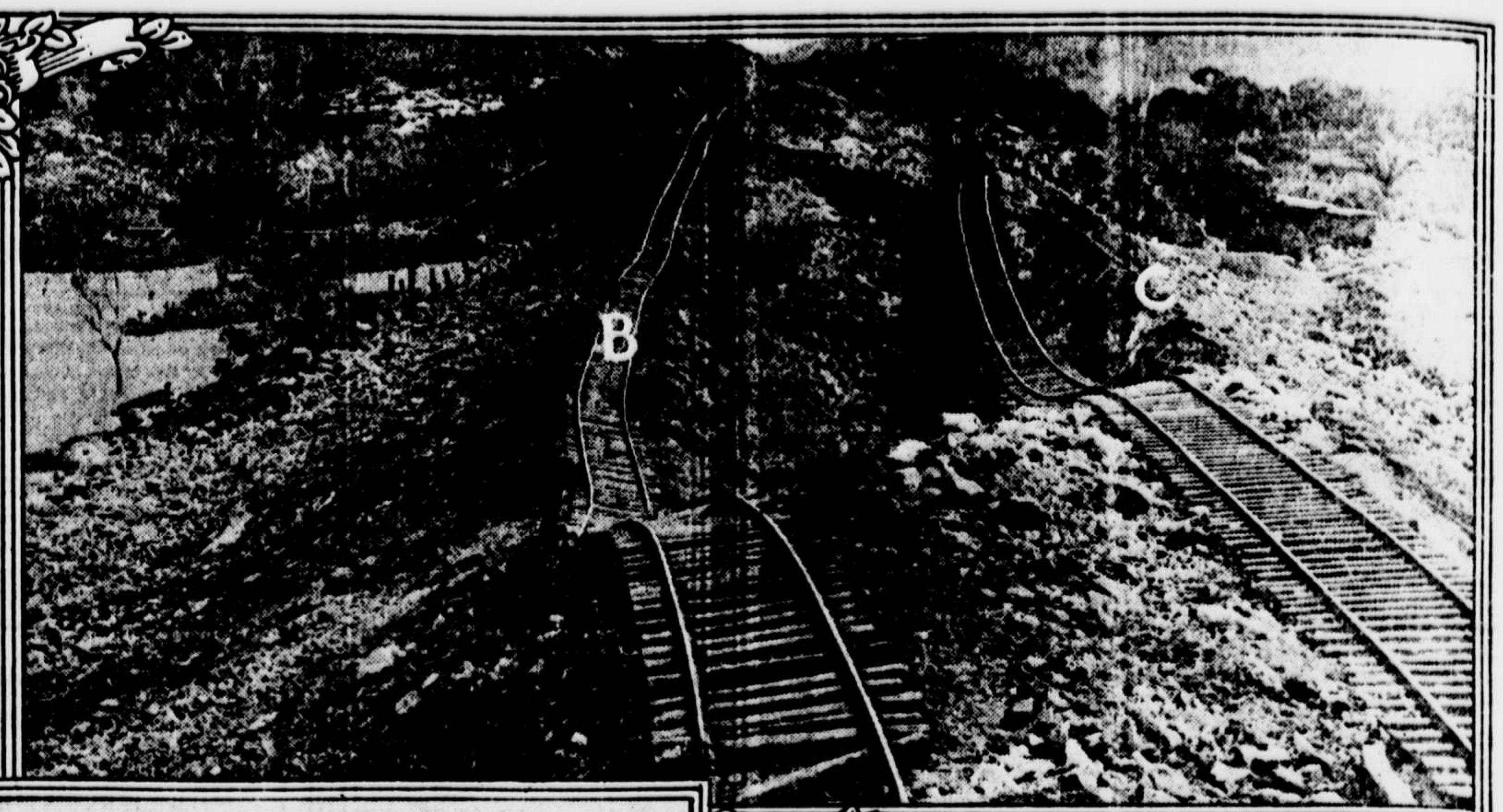
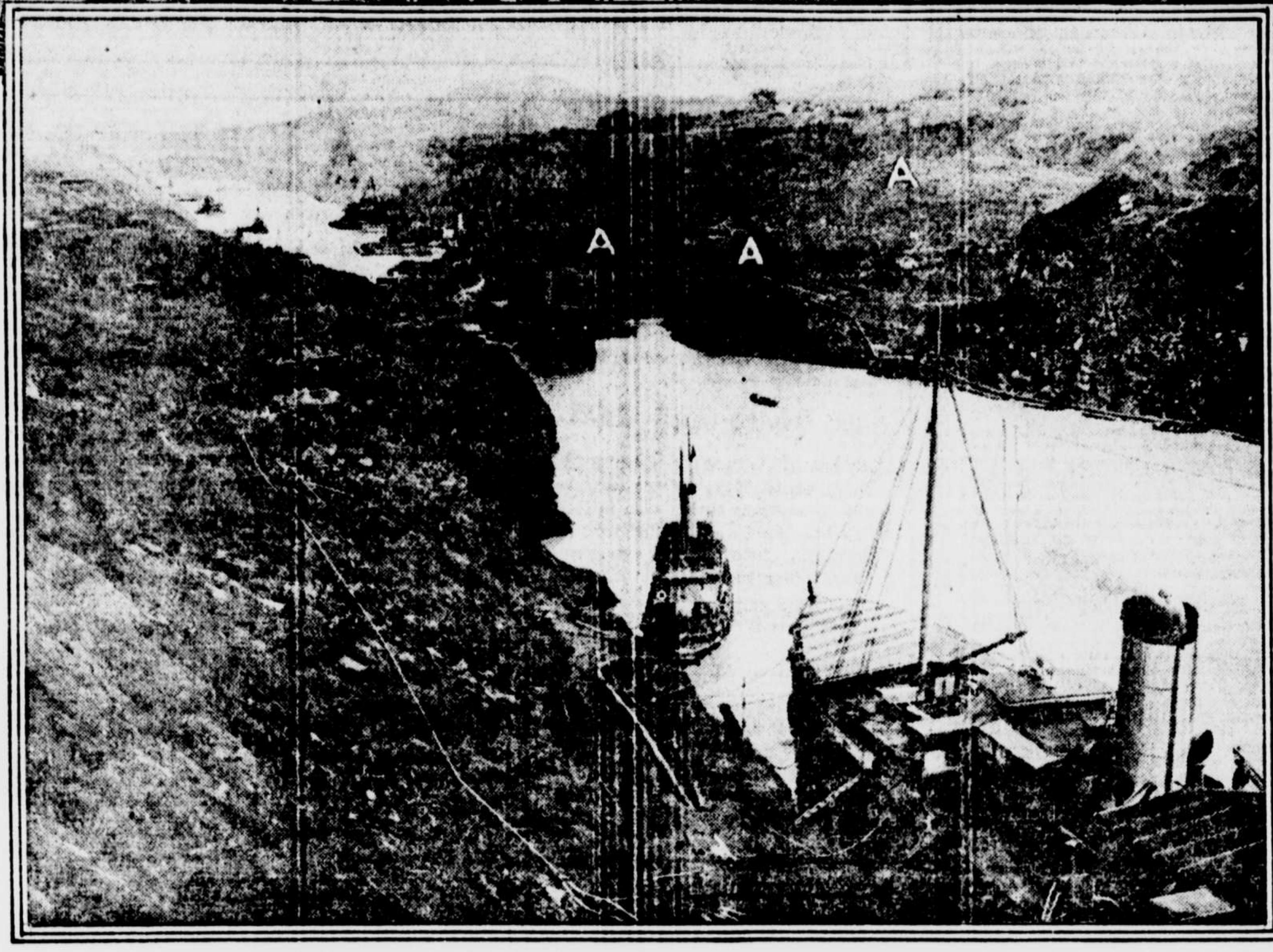
GENERAL GOETHALS TELLS OF THE MIGHTY PROBLEMS FACED BY HIM AS CANAL BUILDER



The difficulties of steam shovel work on a slide.



Weak underlying strata pushed up (A) by weight of embankment (B); spread (C) not sufficient to produce equilibrium.



Complete closure of the canal. Waves that are moving down shown at "A."

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it be necessary to increase the height of the embankment after troubles of this kind have started they are cured by extending the base of the superimposed mass sufficiently to establish equilibrium; the extent to which this blanket should be carried is determined experimentally.

Soft Earth Forced Up.

If instead of building up an embankment on ground so constituted a trench be cut through it the removal of the material from the cutting will change the distribution of the load of the adjacent banks, and if the excavation be carried deep enough results will be produced similar to those in the foregoing case of the embankment, i. e., either the soft or underlying strata will be forced into the excavated area or the bottom of the latter will be pushed up, when rupture is caused before the bottom of the excavation reaches the weaker layer.

In either case the bank above the broken strata is ruptured and there will be a movement of a portion of the bank into the trench, the motion continuing until equilibrium is reached. The trench is filled or partly filled by the material that moves in, and when this is taken out additnonal material may break away, and so the operation continues until final equilibrium and ultimate stability are secured unless, as in the case of the embankments, some means can be adopted to reduce the load of the adjacent banks other than allowing all the material to enter the prism for removal. The results which follow in the foregoing cases are modified through extraneous causes, such as alternate freezing and thawing and excessive moisture due to rains or snow.

The foregoing behavior of various materials under varying conditions explains the causes of the slides that have been encountered in the construction of the canal. They occurred at points all along the line from the lower end of Gatun locks to the sea level section south of Miraflores locks, both in building embankments and in various excavations that were made. They were encountered early in the construction of the Sosa-Corozal and Gatun dams.

Causes of Displacement.

In the former, due to the weak strata underlying the surface, there was caused a bulging up outside of the embankment, with a consequent settlement and displacement of the pile. The slip which occurred in the rock pile which formed the southern toe of the portion of the Gatun dam near the edge of the old French canal and which brought forth such adverse criticism of the project at the time was caused by dumping rock on a comparatively soft and slippery material.

On the relocation of the Panama Railroad high embankments were built on ground underlying which were relatively soft strata that could not bear the pressure transmitted to them by the superimposed masses.

Depending upon the causes, the slides which were encountered while excavating for the locks and the canal prism were of three distinct classes. First, those caused by the material assuming its natural slope, in cases where the banks were left steeper than the angle of repose for the particular material through which the excavation was carried.

Second, those due to the fact that material more or less permeable reposed on relatively harder strata, which inclined toward the cutting. When the excavation reached a level near or below the intersection of the harder plane with the sides of the prism the superimposed mass moved into the excavated area.

Third, those which resulted from the breaking of weak strata underlying the banks, rupture being produced by the concentration of the weights of the banks due to the removal of the material from the prism.

Slides and Breaks.

The first two classes were designated "slides." With the third class the cause was the breaking up structurally of the natural material, and they were called "breaks" in contradistinction to the slides, although after the break occurred the movement of the mass above the fractured strata into the excavated area produced the same general effect as a slide of the other classes.

The first class gave relatively little trouble and ceased entirely when the natural slope of the material was reached. The second class usually brought in quantities of material suddenly, at times burying or overturning steam shovels and tracks, interrupting drainage and causing considerable delay and additional expense. In these cases when the material reached the angle of repose which the conditions imposed there was no further trouble.

The third class or breaks were the most serious and difficult slides encountered, and our present difficulties are due to breaks, two in number, on opposite sides of the canal in the vicinity of Culebra, north of Gold Hill. While breaks occurred at various places along the line of the canal, those in Gaillard Cut, or the excavation through the continental divide, were the most serious, because of the heterogeneous masses of material which composed it and the depth of the cutting, which affected the territory adjacent to the cut for a considerable distance, and therefore brought down large quantities of material.

First Trouble in 1884.

The French company experienced difficulties with a slide at Cucaracha as early as 1884, but all the indications pointed to a surface movement only, and this opinion was supported by geologists who examined into the matter. With the possible exception of the French member, who is said to have been somewhat apprehensive on the subject, the international board of engineers anticipated no difficulties from landslides, as their report clearly indicates, and as does also the testimony of those members of that board who appeared before the committees of Congress dealing with the canal. The slides that were regarded as probable were surface movements of the clay covering the rocks, resulting from the heavy rains, and these were provided for by arranging the slopes in a series of steps on a general inclination of 45 degrees, the angle of repose of ordinary earth.

After the United States forces began work, sliding at Cucaracha continued, and in 1906 a geologist was employed who, after spending some months making personal examination of the geological formation of the country traversed by the canal, made a report on the subject, which was published in full in the annual report of the Isthmian Canal Commission for 1907. In this report he states:

"The relation of the Isthmian geology to the varied problems of canal construction is, in all cases, intimate. One of the problems that is closely connected with the geology is that of the excavation of the cut in the central area. Actual work has advanced so far in this region, however, that geology can add little to the practical information acquired in the course of the excavation that has already been made. A less evident, but perhaps closer, relationship exists between the geology and the problems attendant upon the construction of the locks and dams, while the necessity of obtaining large quantities of building material near the points where locks and regulating works are to be constructed calls for a special study."

Value of the Geologist.

From this it would appear that the excavation in the cut would be attended with few difficulties other than those which are usually encountered in work of such character and magnitude, and that the services of a geologist in connection with the canal would be of value with respect to the locks and the construction materials required therefor, rather than the excavation through the continental divide. However, he discusses subsequently, in the same report, the conditions of the cut in the vicinity of our present difficulties, in a manner still more explict, as follows:

"The physical character of the Culebra beds, consisting as they do of alternating layers of sandstone and shale, is peculiarly favorable to landslides. Structurally, however, the strata are so nearly horizontal, or have such low southerly dips north of Gold Hill, that movements involving large masses of rock are improbable, while slopes of suitable angles will do away with the danger of minor slips.

"Gold Hill is bounded on the north and south by faults, the mass of the hill having sunk with respect to the rocks on the other side of the faults. During the process of faulting the strata were twisted to the eastward, and now have steep dips in that direction. This structure is also complicated by large masses of intrusive basalt which were included in the Culebra beds prior to the faulting. The induration resulting from these intrusions has been so extensive that all the rocks in Gold Hill are now very hard and firm, and with the sedimentary beds dipping into the hill the conditions are such that landslides are most unlikely to occur.

Soft Beds in Culebra.

"In Contractor's Hill a heavy breccia member of the Culebra beds dips in the direction of the cut. It is believed that the soft Culebra beds will be encountered below the breccias. If these beds are found to have strong northeasterly dips—that is, if they are inclined in the direction of the cut, as the surface indications suggest—it will be necessary to make comparatively low slopes on the southwest side of the canal at Contractor's Hill in order to avoid any possibility of landslides. This is the only point along the canal where such movements are at all possible. In my opinion, the danger is not serious, but ordinary prudence requires that if the soft Culebra beds are found beneath the breccias to dip at angles of more than 15 degrees in the direction of the cut the angle of slope be so reduced as to do away with all danger of slipping.

"Between Gold Hill and Cucaracha, on the northeast side of the cut, landslides have taken place frequently in the rainy season. The materials involved in these slides are purely superficial; in some cases French spoil banks have slipped. The cause in all cases seems to be the saturation of the unconsolidated surface material and its movement on layers of slippery clays either in the Culebra beds or residual clays upon which spoil was dumped.

"The basin south and east of Gold Hill collects large quantities of water during the rainy season, and this escapes through no well defined drainage, but in springs along the edge of the cut. In some cases surface soils or even the rock of the Culebra formation may take place in these landslips. They are not serious, however, and although they may continue in a minor degree for a number of years, the removal of the material before it reaches the edge of the cut and the gradual reduction of the slopes back of the cut will stop this trouble. The French attempted an elaborate system of drainage to overcome the difficulty, but this has been proved entirely inadequate, and it is improbable that any system of this sort would be practical or economical."

Contractor's Hill Weak.

So far then as the geologist could foresee, difficulties north of Gold Hill were improbable, and if any occurred they could be easily overcome and prevented by suitably sloping back the sides of the excavation. The weak place along the line, the locality to expect landslides, was on the southwest side of the canal at Contractor's Hill, provided the beds below the breccias dipped at greater angles than 15 degrees. This locality was carefully watched, but the slides that occurred there were small and caused but little trouble.

The geologist's report gives correctly the conditions at Cucaracha as he found them, but the predictions in other respects regarding it were not realized, for, except the breaks that now close the canal, it was the most difficult of all the slides to handle. As described, it was a typical slide of class two, and continued so, giving more or less serious trouble until a rock dike was uncovered in 1910.

This dike seemed to possess ample strength to hold back the great mass of clay remaining on the levels above it, and the movement that continued after the rock mass was uncovered was well defined, flowing on either side of it; after motion ceased the heavy rains washed down clay from above, but this caused no particular trouble. In this vicinity the clay movement resembled that of a glacier and in the fall of 1907 so effectually blocked the prism that steam shovels could make no headway and recourse was had to sluicing a passage through for the tracks. Subsequent movements interrupted transportation, but the troubles gradually lessened until the dry season of 1910-11, when they ceased entirely.

The difficulties encountered elsewhere because of slides increased and they became so troublesome that in the latter part of 1910, at the suggestion of Dr. C. W. Hayes, chief geologist of the Geological Survey, who examined the various localities on the Isthmus where movements had occurred or were in progress, a geologist recommended by him as having had the necessary experience for such work was employed to assist in the excavation. It seemed possible that through this expert advice some of the movements at least might be avoided.

At Work Three Years.

Donald F. MacDonald, the geologist so employed, was connected with the work for nearly three years, made a careful study of the formations and materials as the excavation progressed and was helpful with his advice and suggestions. He was convinced from a study of the situation that our difficulties at Cucaracha were at an end and that while some of the clay on the upper levels might move into the cut, the amount would be so small relatively that it could be handled easily and without material interference with the other operations, for the dike which had been uncovered would hold.

Unfortunately these expectations were not realized. When the rock mass forming Gold Hill, at the original continental divide, was pushed up through the formation existing at the time its molten mass overflowed the adjacent beds so that it has the shape of a mushroom. The movement at Cucaracha had pulled out the support of part of the overflow, which to some extent, seamed and unsupported, broke off, causing a rock slide south of the hill in the middle of January, 1913. This was followed on January 20 by a typical "break" at Cucaracha, by which the rock bluff which was holding back the upper mass of clay broke at or below the bottom level of the canal, completely filling the prism with clay and rock, reaching to sixty-nine feet above sea level on the opposite or west side of the cut.

The length of the prism so filled was 1,600 feet. Steam shovels were scarcely able to keep pace with the movement, tracks were covered and disarranged, shovels overturned and the difficulties of transportation increased, since only tail tracks sufficient for two or three cars could be maintained. Furthermore, the soft material increased the difficulties on the dumps. As the movement continued the clay broke further and further up the hillside.

Sluice Found Handy.

There was still a large quantity of material near the tops of the hills forming the basin from which the material was moving; there was a sluicing plant that had done the work for which it was origanally purchased; the configuration of the ground on the reverse side of the hills lent itself admirably to sluicing operations; and this method of removing the upper portions was adopted. Upward of 1,000,000 cubic yards, which in all probability would have moved down into the prism, were removed by sluicing at a cost of 20 cents a cubic yard.

In the meantime the remainder of the cut was nearing completion, ready for the admission of the water, and the question of continuing the removal of the balance of the slide by steam shovels or by substitution of the dredges which were available was considered. The slide had occurred in January; as many steam shovels were concentrated on the slide as could be worked to advantage; it was estimated that the removal of 2,000,000 cubic yards would clear the prism and that the bottom grade would be reached by June. During February eight steam shovels removed 168,677 cubic yards, six shovels working during March and April removed 203,030 and 204,308 cubic yards respectively, but these were dry season months.

The rainy season set in and reduced the output of the same number of shovels during May to 148,000 cubic yards and during June to 124,844 cubic yards. The expectation of reaching the bottom at this time was not realized. The cost of excavating material from the slide was not segregated from that of the balance of the cut; the cost of removing 921,000 and 808,000 cubic yards from the entire length of the cut, including Cucaracha, during May and June was 62 and 66 cents per cubic yard respectively. Difficulty was experienced in maintaining tracks, not only at the slide but on the dumps, and with the months of heaviest rainfall still ahead the difficulties and the cost would be increased.

Dredging Best Means.

The available dredging fleet was capable of handling larger quantities of material than this number of steam shovels; the dredges could work twenty-four hours per day, while the shovels could work not to exceed twelve hours. There would be no tracks to maintain, for the waterway itself furnished the transportation route, and there could be no trouble at the dumps, which would be various indentations in the lake. All indications pointed to dredging as the best means of removing the balance of the slide.

Another factor was taken into consideration. It was the belief that the effect of the water would tend to retard the slides, through the counteracting effect of the weight of the volume of water, and this belief seemed justified from the experience gained with the slide below Gatun locks. On the other hand, the geologist held the opinion that the water might to some extent develop the slides; if this were to be the case, then the sooner this fact were developed the better. Mr. MacDonald's views are expressed in his report incorporated in the annual report of the Isthmian Canal Commission of 1912, as follows:

"The turning of the water into the canal will remedy the slides in so far as it will provide cheaper methods of excavation and removal of them by dredging. The counterbalancing effect of the water against the slopes of the canal will be very small so far as the slides are concerned, for the following reasons: The maximum depth of water in Culebra cut will be forty-five feet and the height of the slopes where sliding might occur is from seventy-five to 300 feet. The sliding material has an average specific gravity of about 2.5, hence 45 feet of water will balance about eighteen feet of slide if the pressures were evenly distributed.

"Considering the more or less wedged shaped fronts and the back pressures of many of the slides, it is estimated that the forty-five feet of water would be equivalent to only about ten feet of slide pressure. Other considerations are that, though the water will protect the lower part of the canal from oxidation and weathering, thus removing a small source of weakness, it will cause water to permeate under pressure the cracks and interstices at the foot of the slope and thus be an added source of weakness—though not a serious one—to the slides. On the whole, the water in the canal will slightly increase the tendency to slide, but this will be much more than offset by the cheaper methods of excavation and transportation which can then be used."

Water was admitted to the cut on October 10, 1913. The dredges reached Cucaracha slide on October 23, 1913, and up to August 3, 1914, on which date the first ship went through the canal, the removed 2,767,080 cubic yards, or an average of 286,239.78 cubic yards per month. The steam shovels working from January 20, 1913, to September 11, 1913, when steam shovel operations ceased, removed a total of 1,139,708 cubic yards from the slide, or an average of 142,463.4 cubic yards per month. The cost of the dredging for the period mentioned averaged 44 cents per cubic yard, while the cost of the steam shovel operations for a total of 8,225,989 cubic yards removed from the entire length of the cut during the period considered, including Cucaracha, was 65 cents per cubic yard.

The third class of slides, or "breaks," began in 1907, at the village of Culebra, and those in this vicinity have been the most serious and troublesome. The first one manifested itself when the excavation had reached a depth of approximately 100 feet below, near the old Panama Railway station, by a crack in the surface of the ground, extending from one point on the prism slope to another.

Lifts Steam Shovel.

Subsequent to the appearance of the crack there was a subsidence of the surface on the side of the crack furthest from the prism, accompanied by an upward movement of the bottom of the excavated area and followed by the settlement of the mass between the crack and the cut with ultimately a sliding in of this mass into the excavated area. In some of the subsequent movements of this kind the upheaval of the bottom was sufficient to lift a steam shovel standing on the portion pushed up. The first break affected but a few hundred feet, but as the depth of the excavation increased the breaks became more extensive both in length and quantities of material involved; furthermore, they occurred on both the east and west banks, until the upward movement along the bottom of the excavated area affected a length of 2,000 feet north of Gold Hill.

The borings of record failed to disclose any weak underlying strata. The cause undoubtedly was the unequal distribution of the pressure exerted by the adjacent banks. Such being the case it followed that if the height of these banks were reduced the movement would be lessened, and if reduced sufficiently would cease entirely. Opposition developed to this method on the ground that more material would in all probability be removed than was necessary; that by allowing the material that broke off to move into the cut the minimum amount would be handled, resulting in reduced costs, and the material left to itself would assume the natural slope that would result in rest under the conditions that existed.

The difficulty was that each break overturned the tracks at the bottom of the excavation, interrupted drainage, thus seriously interfering with and delaying operations in the prism, not only in the vicinity of the break but at the localities where the shovels were drowned out through the stoppage of drainage or where the train service to and from shovels depended upon the overturned or broken tracks. The expense involved by this condition would more than offset the cost of any excess of material, if any, that might be moved from the upper levels.

Two Breaks in 1910.

Two breaks occurred in rather rapid succession at Culebra in the latter part of 1910. The usual interruption of work occurred. The later one of the two determined the change in plan and in January, 1911, the reduction in the height of the adjacent banks on both sides of Gaillard Cut in the vicinity of Culebra was directed and begun. Had the adoption of the method been delayed there would have been other difficulties attending the lightening process, for the outlet to the main line would have been cut off and there would have been a very material increase in cost to arrange for the transportation of the spoil.

The geologist after examining into the situation strongly indorsed the lightening of the banks, not alone because of upsetting and delaying operations within the prism but because "each slide of this type deforms and weakens the rocks down below the limits of the material which actually goes into the cut at the time, and this sheared and weakened rock requires much flatter slopes to maintain itself than would have been necessary had it not been strained by pressure and deformation."

The work of lightening both the east and west banks was carried on until December, 1913, at which time 6,533,924 cubic yards had been removed from the east bank and 8,797,990 cubic yards from the west bank, resulting in slopes of from 1 on 1.5 to 1 on 6.5 for the east side, and from 1 on 2.46 to 1 on 4.35 for the west side. The slopes were arranged in a series of benches.

The result of this method of procedure was that when the operations in the cut in the vicinity of Culebra were completed prior to the admission of water the breaks in the banks and the upward movement of the bottom had ceased entirely.

Cracks Come and Go.

When the surface of the ground is exposed to the sun cracks appear during the months of no rain after the sun and winds have dried out the surface. Unless the cracks are of some size caused by prolonged exposure, they close and disappear after the ground is saturated by the rains. During the dry season of 1913 a crack appeared on the east side, opposite Culebra, about 1,300 feet from the prism, in an old French dump. It was parallel to the canal—did not join the banks; there was no breaking up of the bank between it and the cut, nor any subsidence; in short, there were none of the indications that accompanied breaks.

The geologist suggested lightening up the banks, which was done by sluicing and steam shovels, and as no movement could be detected there was every reason to believe that it was not a break, especially as subsequent to this the prism below this section was completed to full width and depth without any indications appearing anywhere in the bottom or sides. A crack had existed for some years at the foot of Zion Hill, southeast of Culebra; the hill was pronounced geologically secure against any movement, and when the material was dug away from the upper portions of the bank and the slopes of the final bench reached the crack it apparently did not increase, and there was no movement. The geologist has marked out the minimum and maximum limits to which in his opinion the breaks might extend, and the excavation on the two banks was extended to practically the maximum limits outlined, in some portions exceeding these limits. Such were the conditions in this section of the canal when water was admitted.

Openings on Both Sides.

In the dry season of 1914 slight cracks appeared on some of the intermediate benches on the two sides in the vicinity of Culebra; whether they were ordinary dry season cracks or the first indications of possible breaks could not be determined though they resembled the former. To guard against contingencies, however, the shovels were returned and worked on the east bank, reducing the slope still more, until April 1, 1914, and on the west bank they continued work until June 14, 1914, by which date